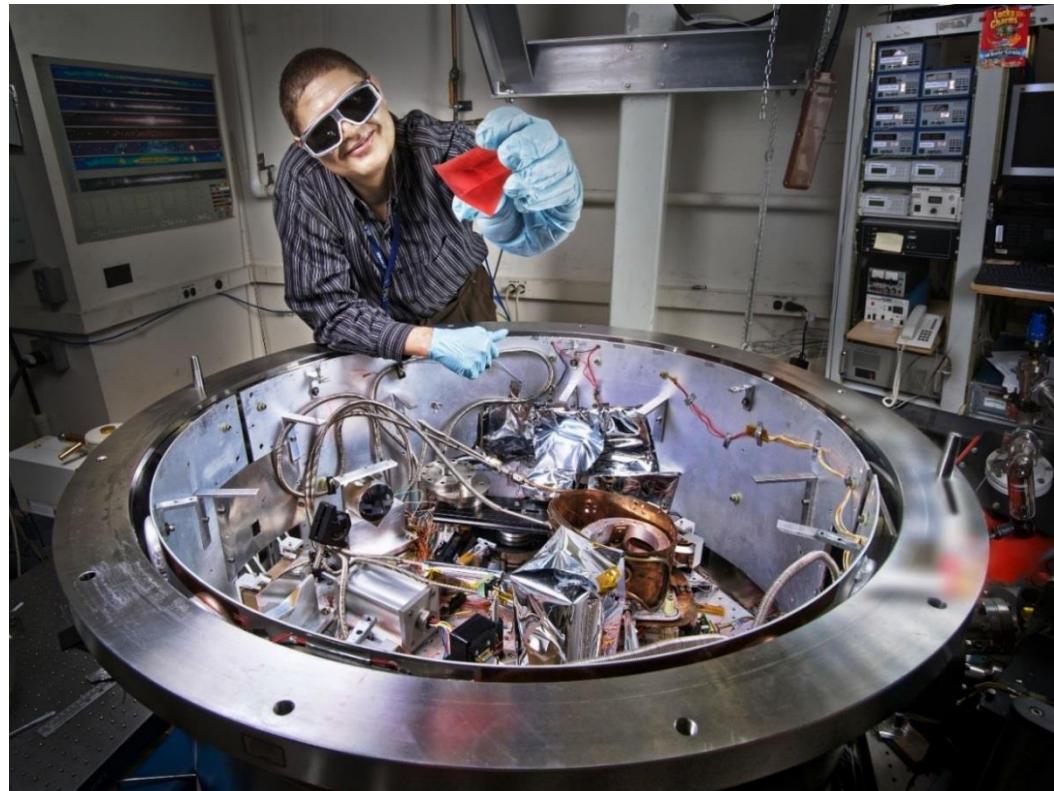


Cryogenic Refractive Index of Heraeus Homosil Glass

Kevin H. Miller

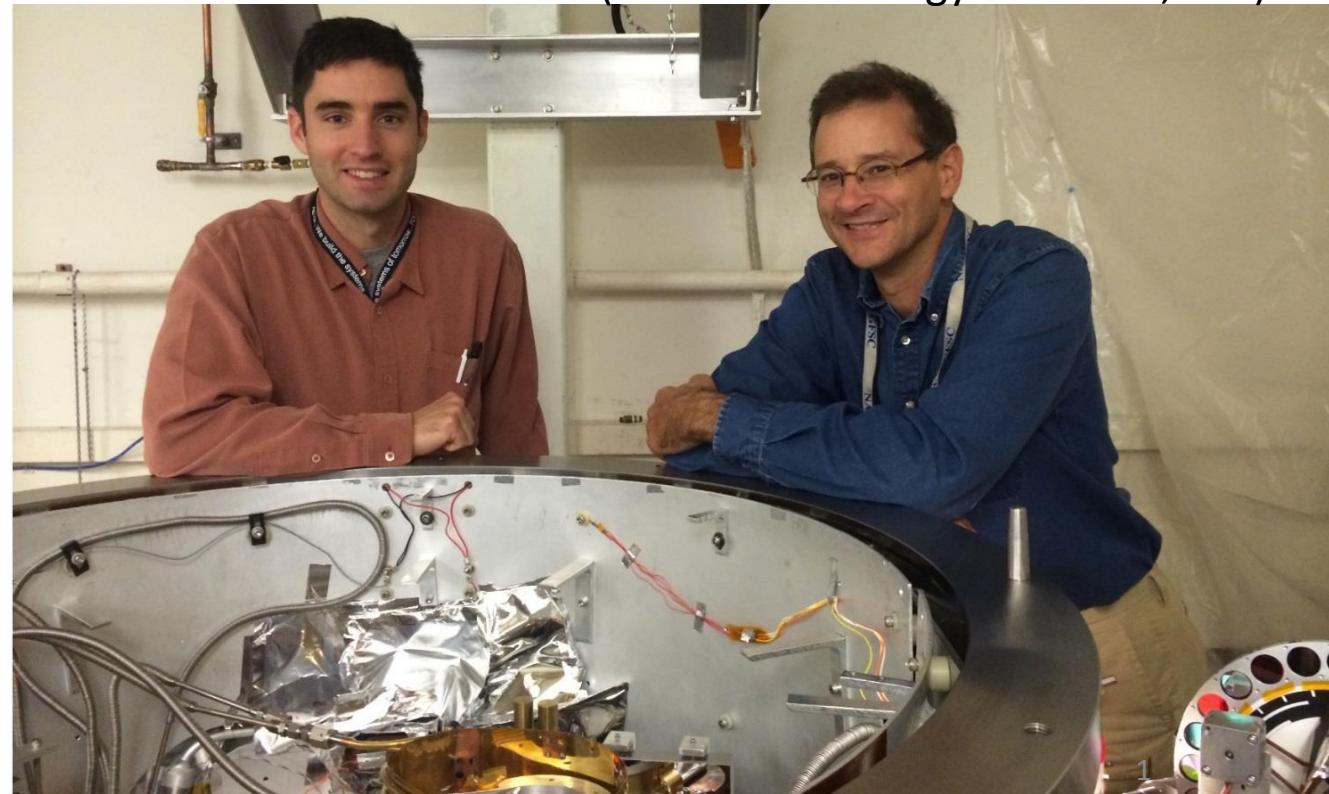
NASA Goddard Space Flight Center, Optics Branch
August 7th, 2017

Manuel A. Quijada (GSFC Optics Branch)



Douglas B. Leviton

(Leviton Metrology Solutions, Inc.)



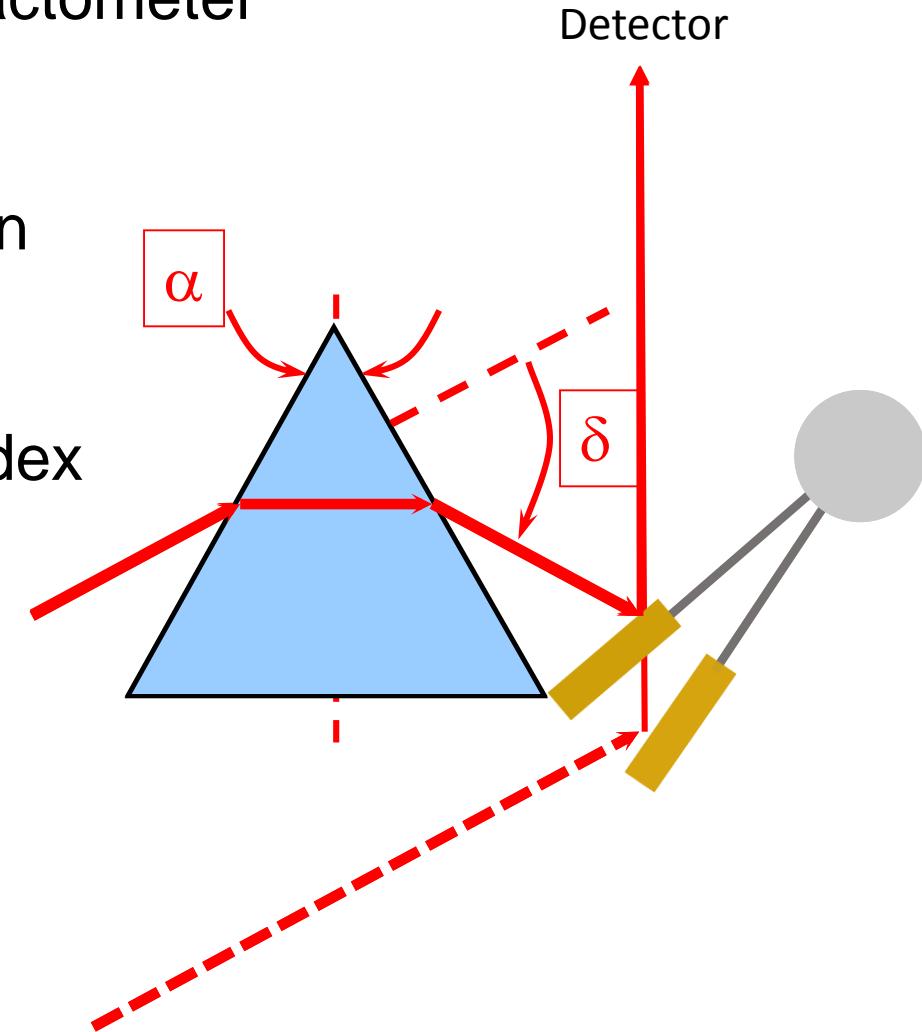
CHARMS Capabilities

- Absolute minimum deviation refractometer (in vacuum)
- Wavelength coverage: 0.34 to 5.6 μm
- Temperature coverage: 15 K (using LHe) to 340⁺ K (67 C)
- Single measurement ABSOLUTE accuracies as good as 5×10^{-6} at cryo (depending on material)
- Measures absolute refractive index, $n(\lambda, T)$
- Accurate values of thermo-optic coefficient, dn/dT , and spectral dispersion, $dn/d\lambda$, derived from measured $n(T)$

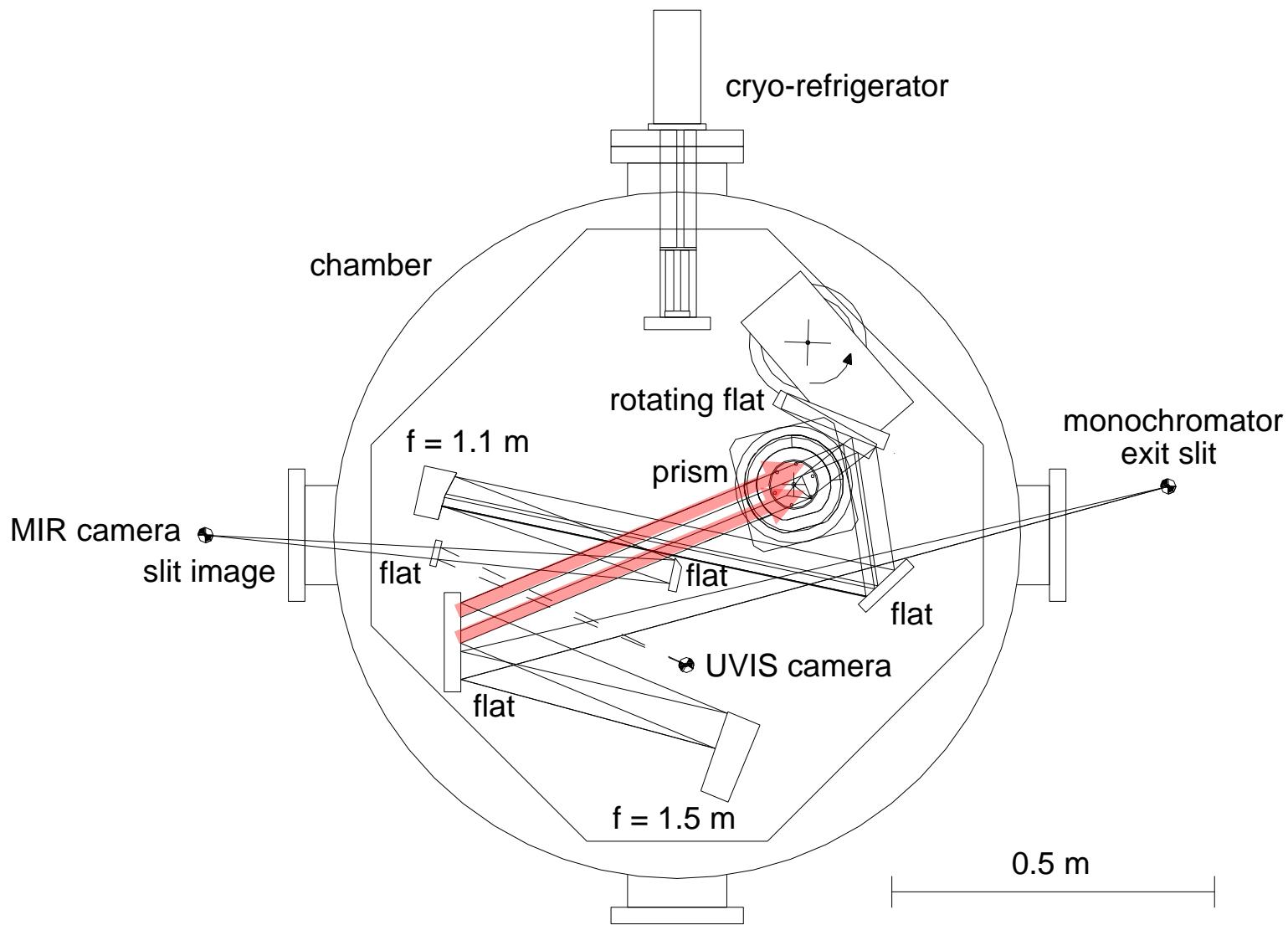
CHARMS: Operation and Capabilities

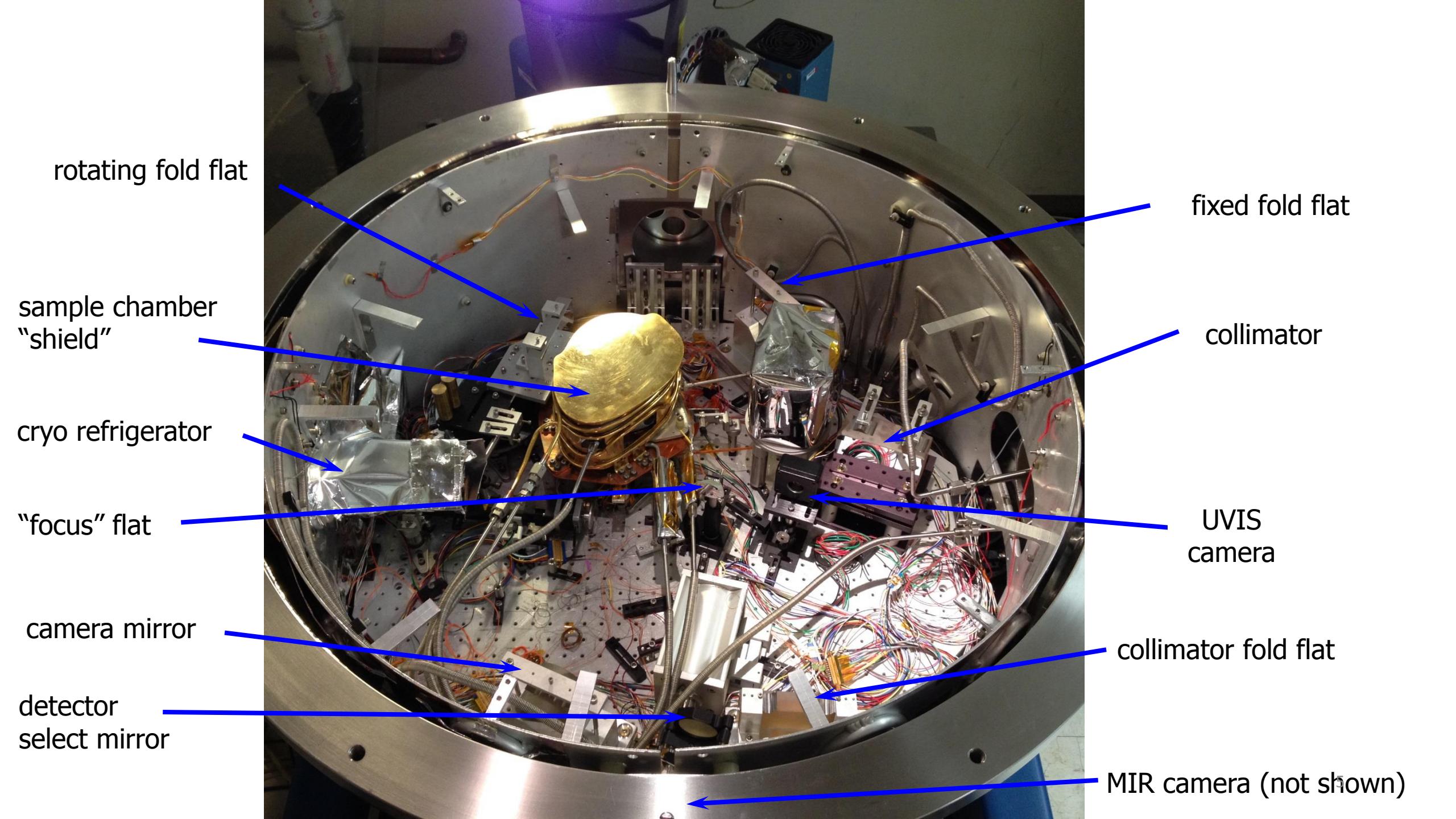
- CHARMS is a minimum deviation refractometer
- Five simple steps:
 1. Measure the apex angle of the prism
 2. Establish the condition of min deviation
 3. Measure angle of undeviated beam
 4. Measure angle of deviated beam
 5. Compute deviation angle; compute index

$$n = \frac{\sin(\frac{\alpha+\delta}{2})}{\sin(\frac{\alpha}{2})}$$

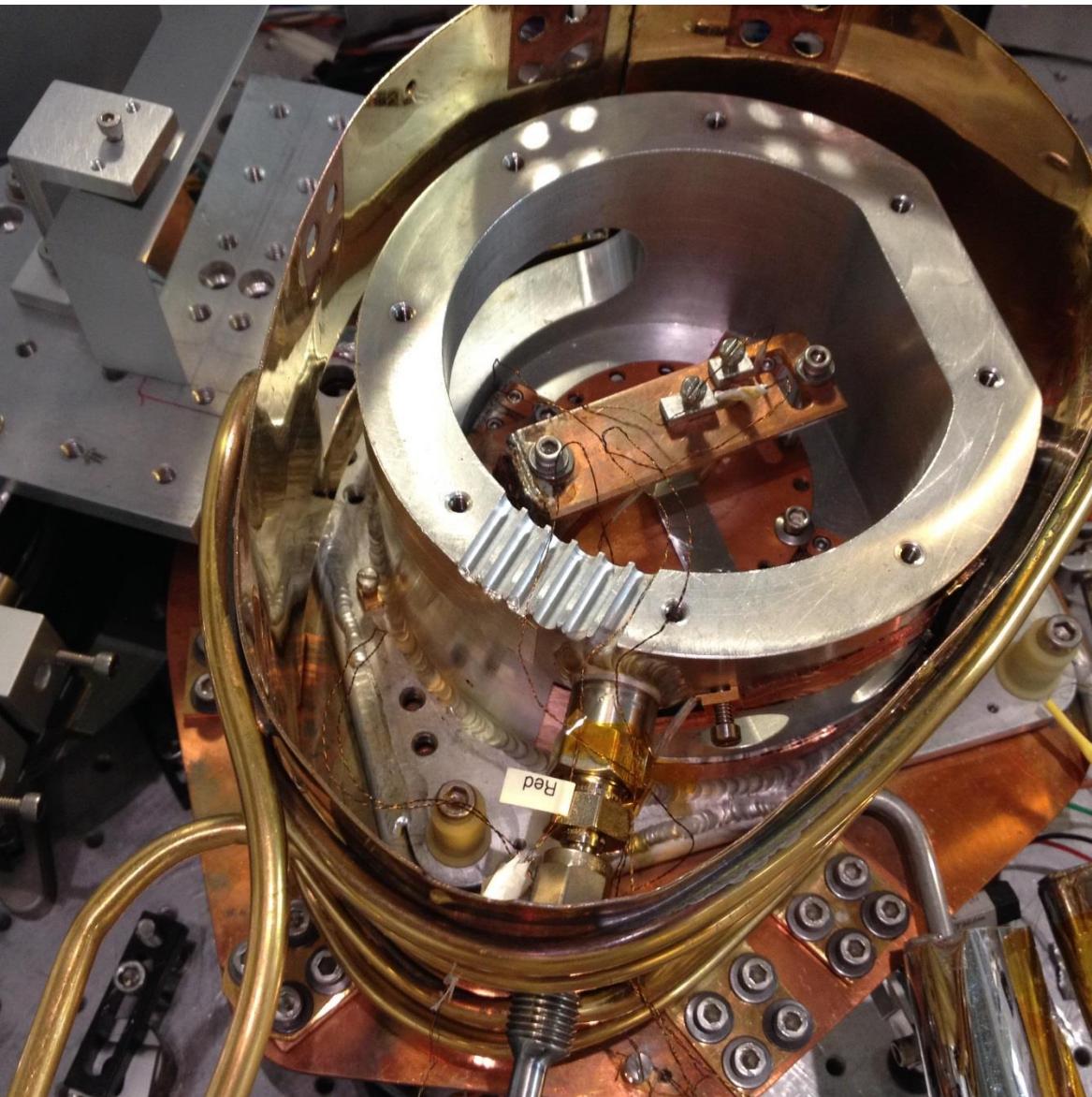


CHARMS optical layout

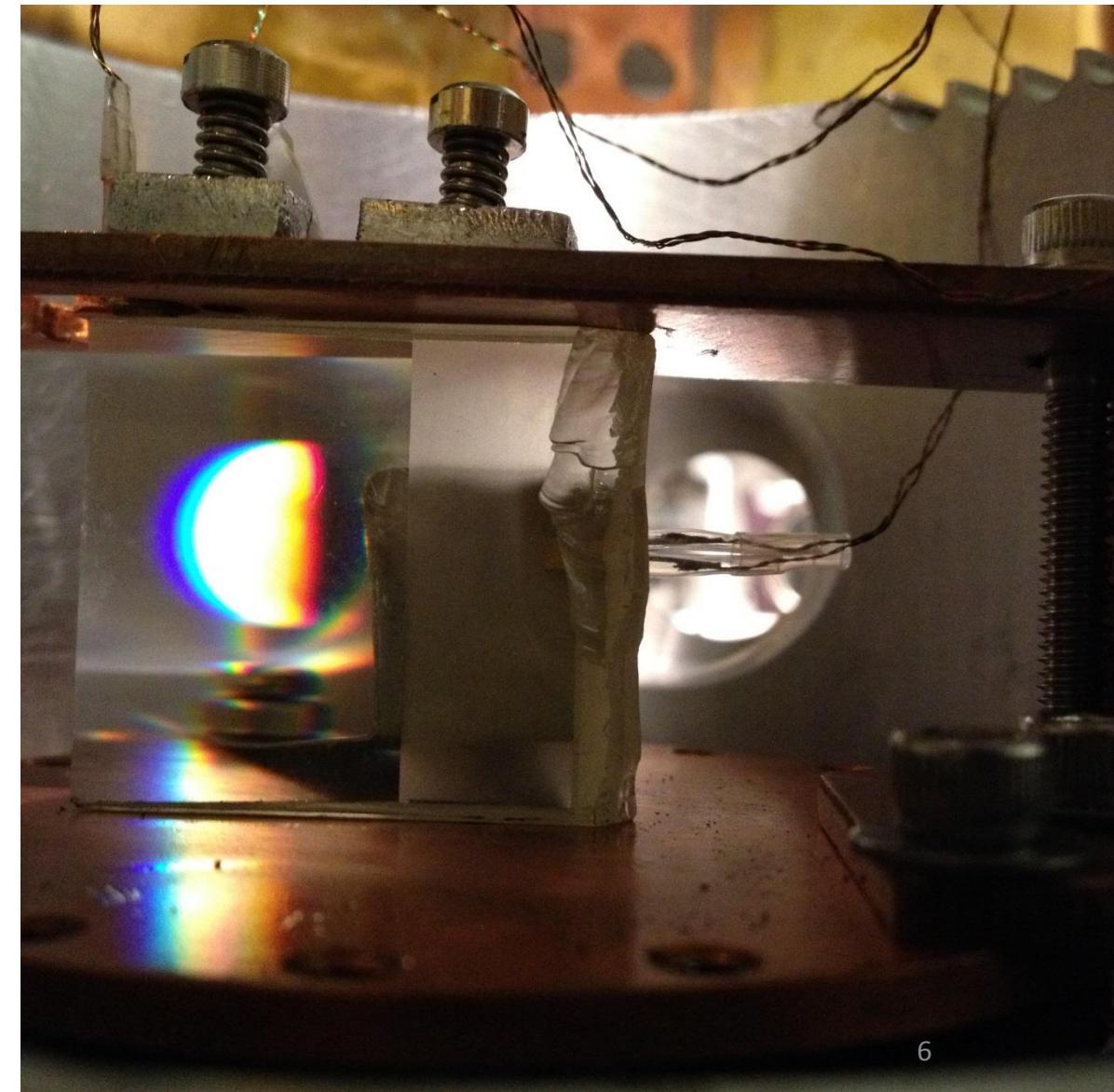




Top view of sample chamber

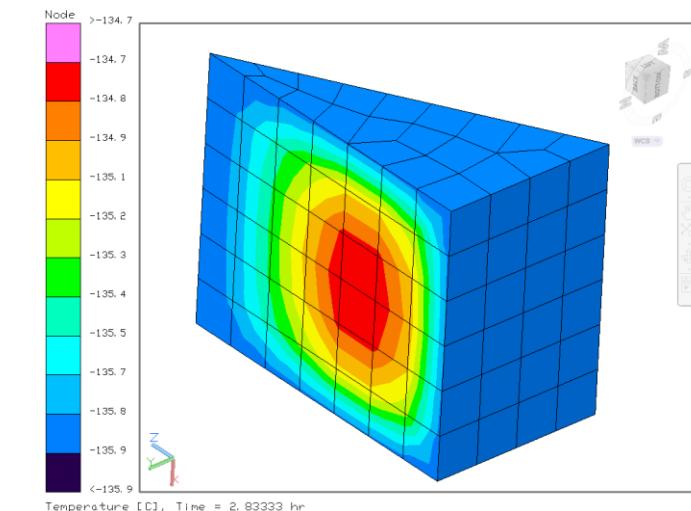
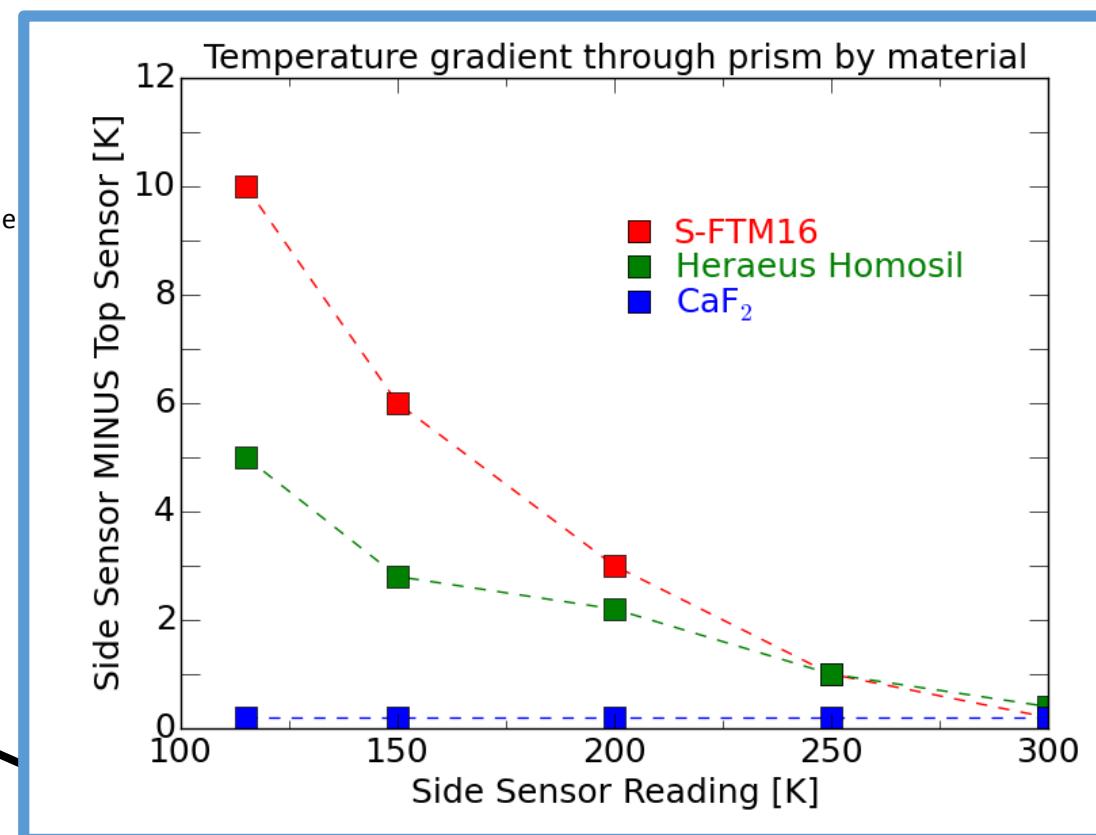
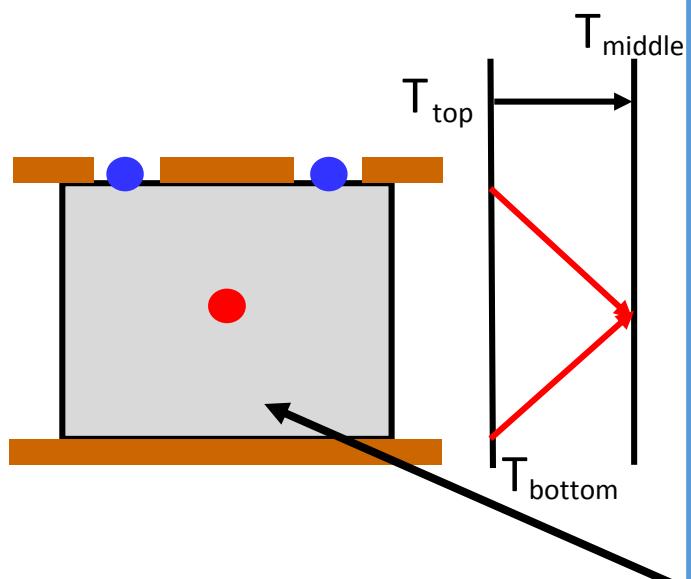


Eye level with prism



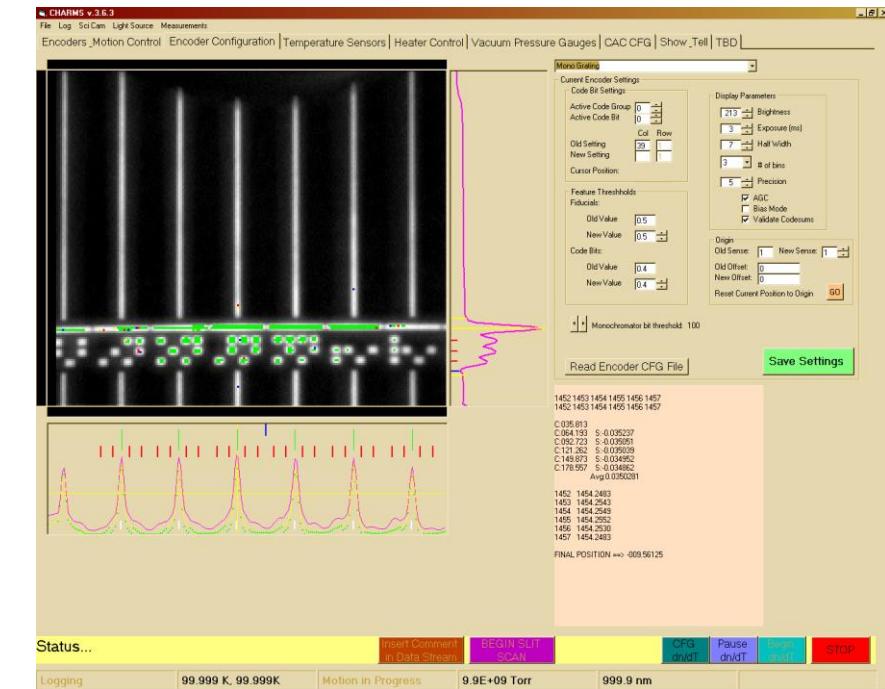
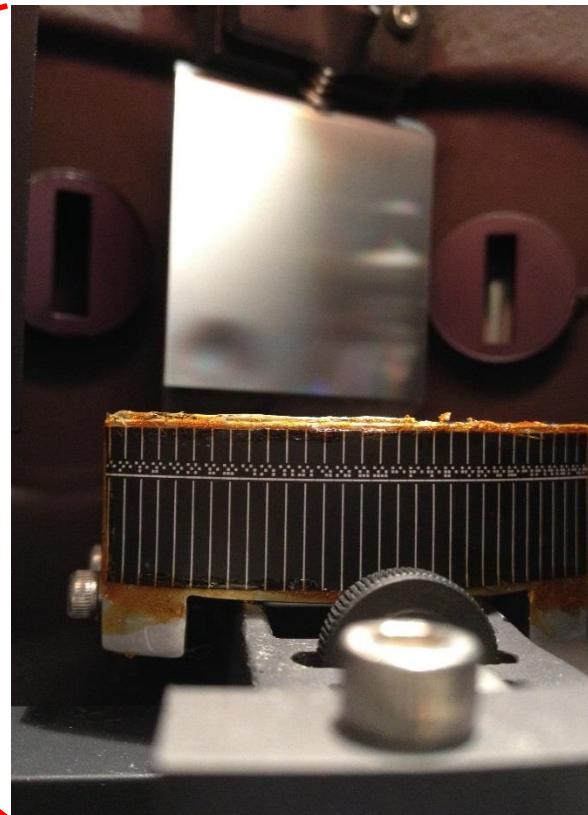
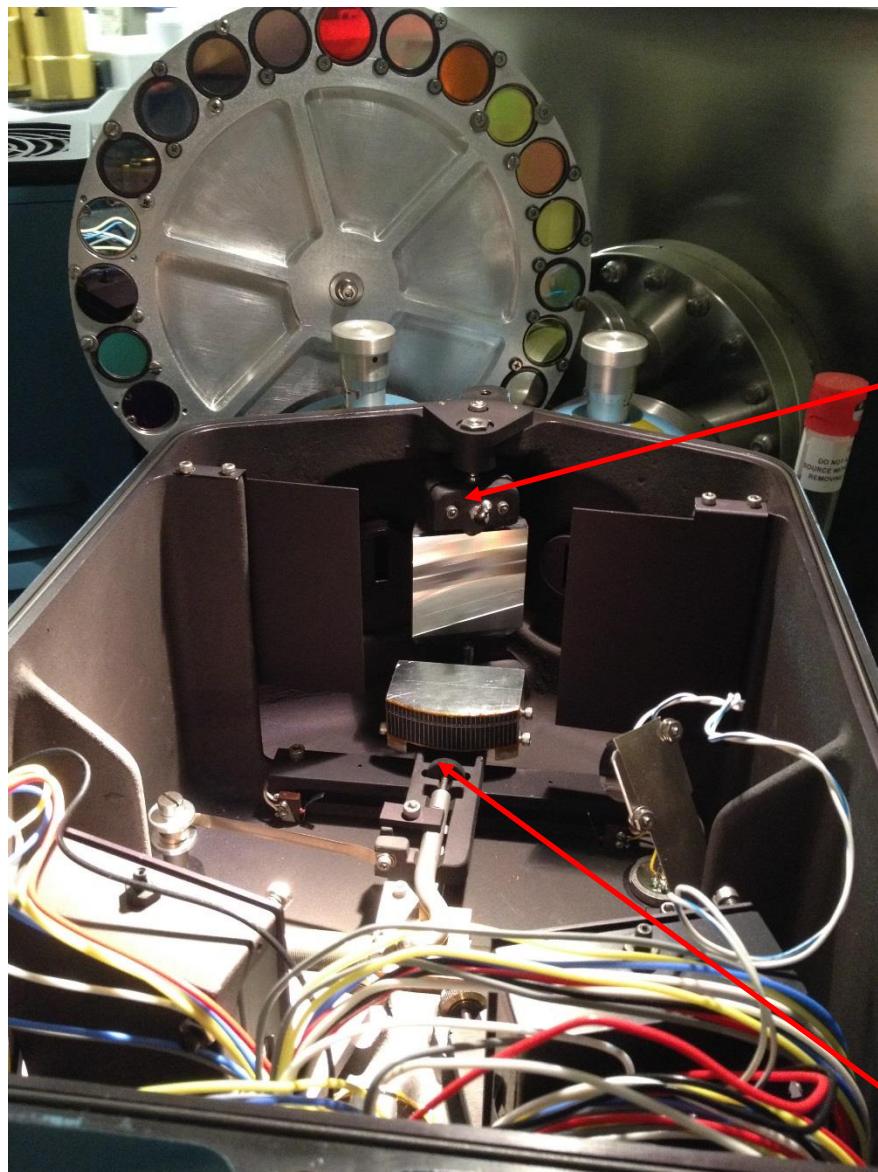
Sample Temperature, T

- sample sandwiched between two cryogen-cooled copper plates at essentially same T
- two T sensors on top of prism
- T_{sample} attributed to reading from sensor halfway up side of non-refracting face



Courtesy of S. Scola –
NASA LaRC

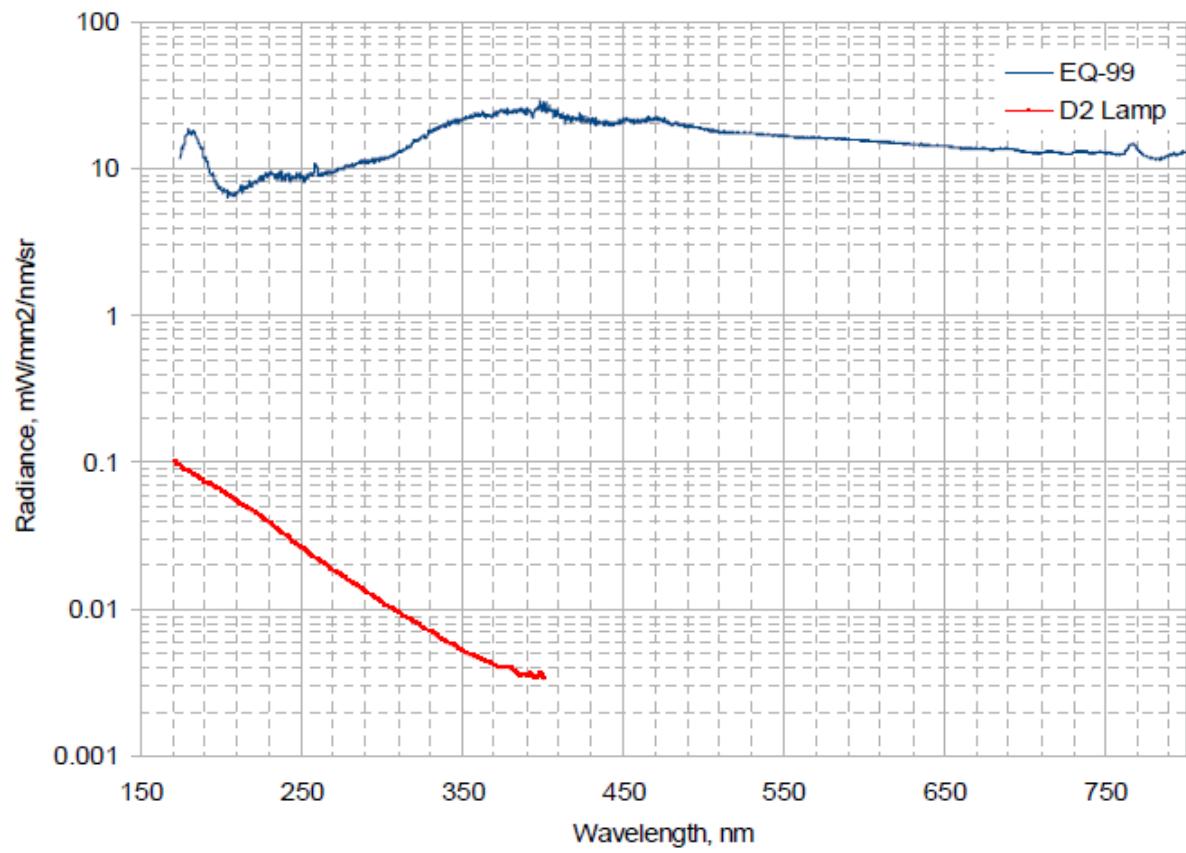
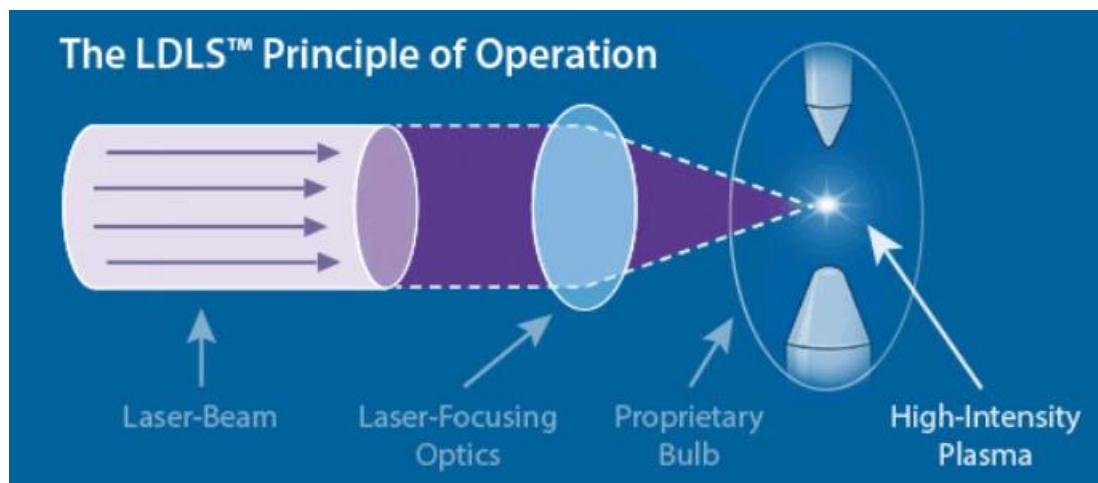
Wavelength Calibration & Encoder Technology



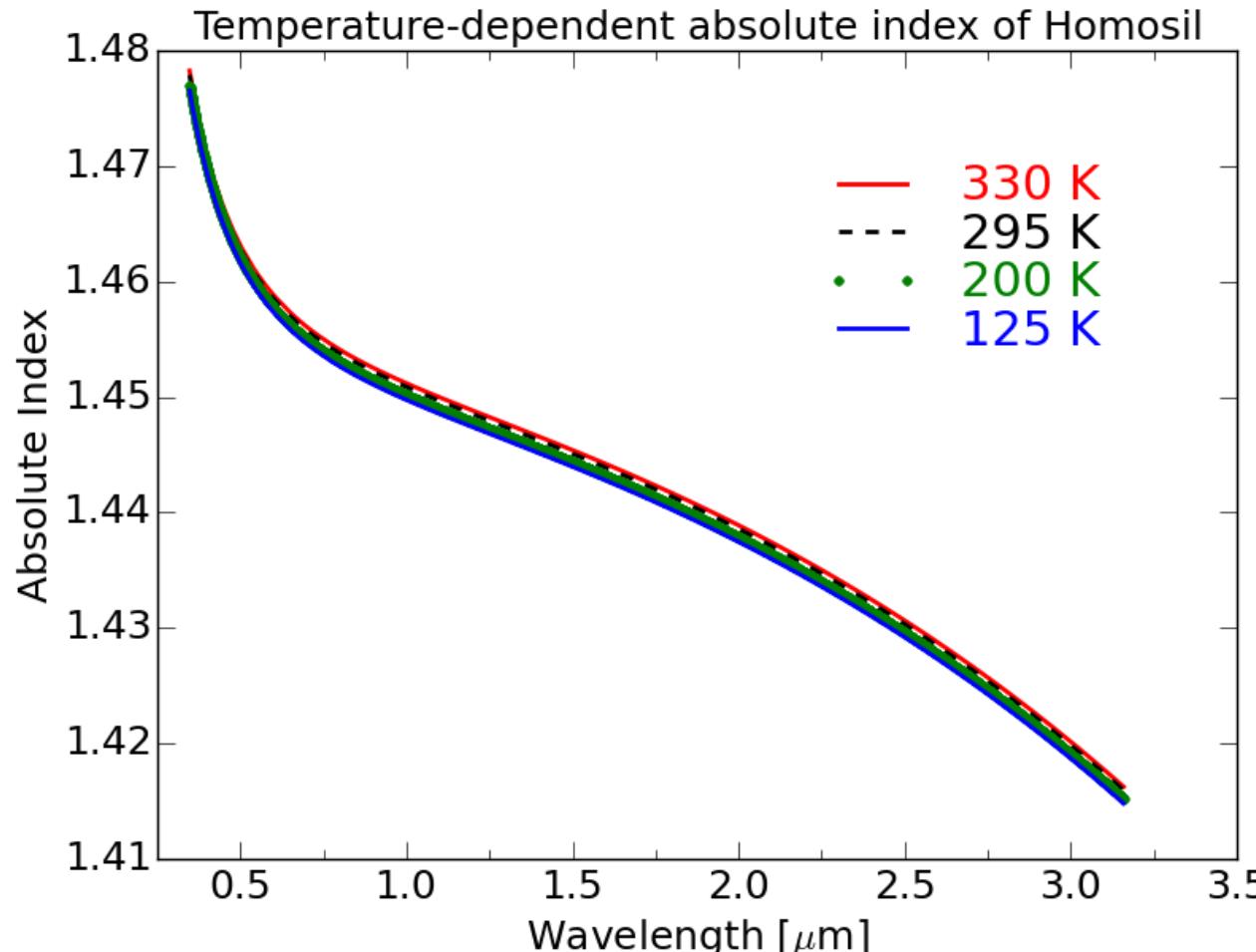
Laser Driven Plasma Light Source

Energetiq 99

- CW laser heats Xenon plasma
- Electrodeless
- 100 micron plasma size



CHARMS Measurements of Heraeus Homosil



Sellmeier Equation

$$n^2(\lambda, T) - 1 = \sum_{i=1}^3 \frac{S_i(T) \cdot \lambda^2}{\lambda^2 - \lambda_i^2(T)}$$

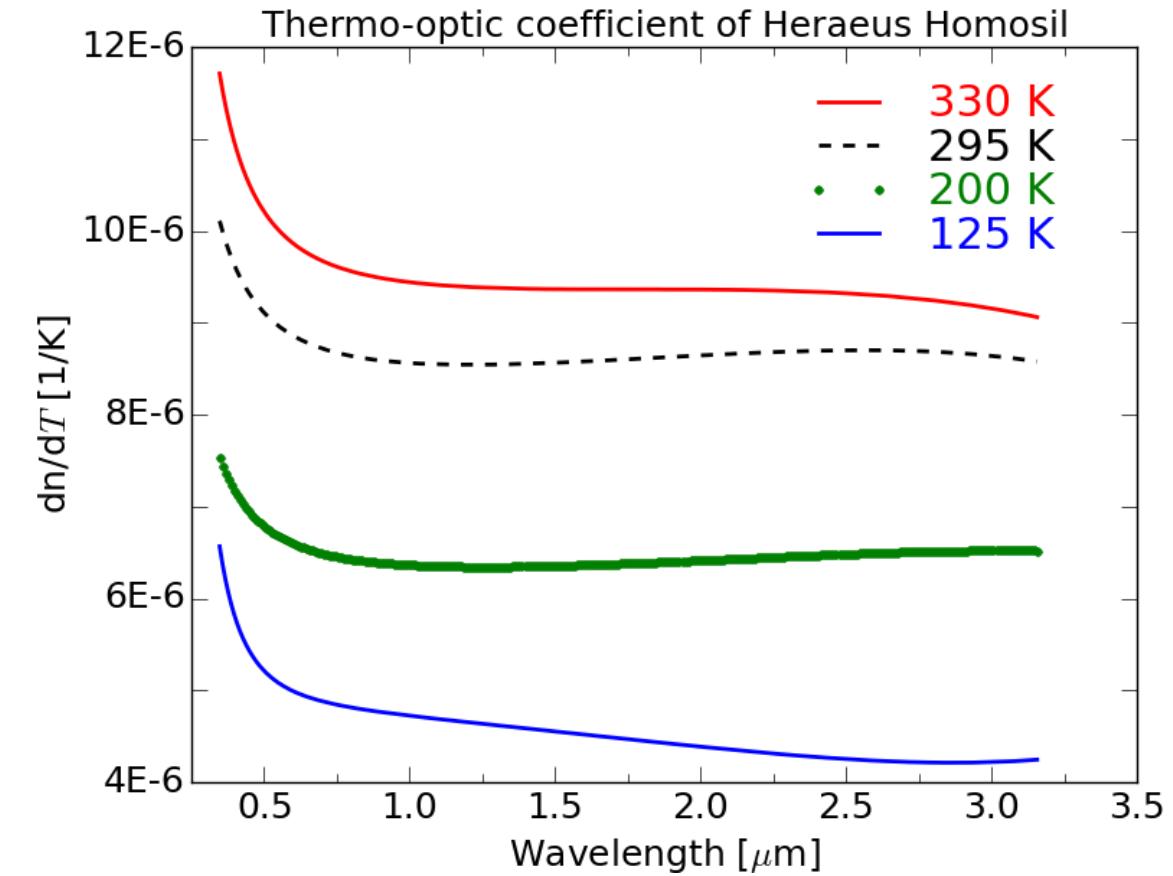
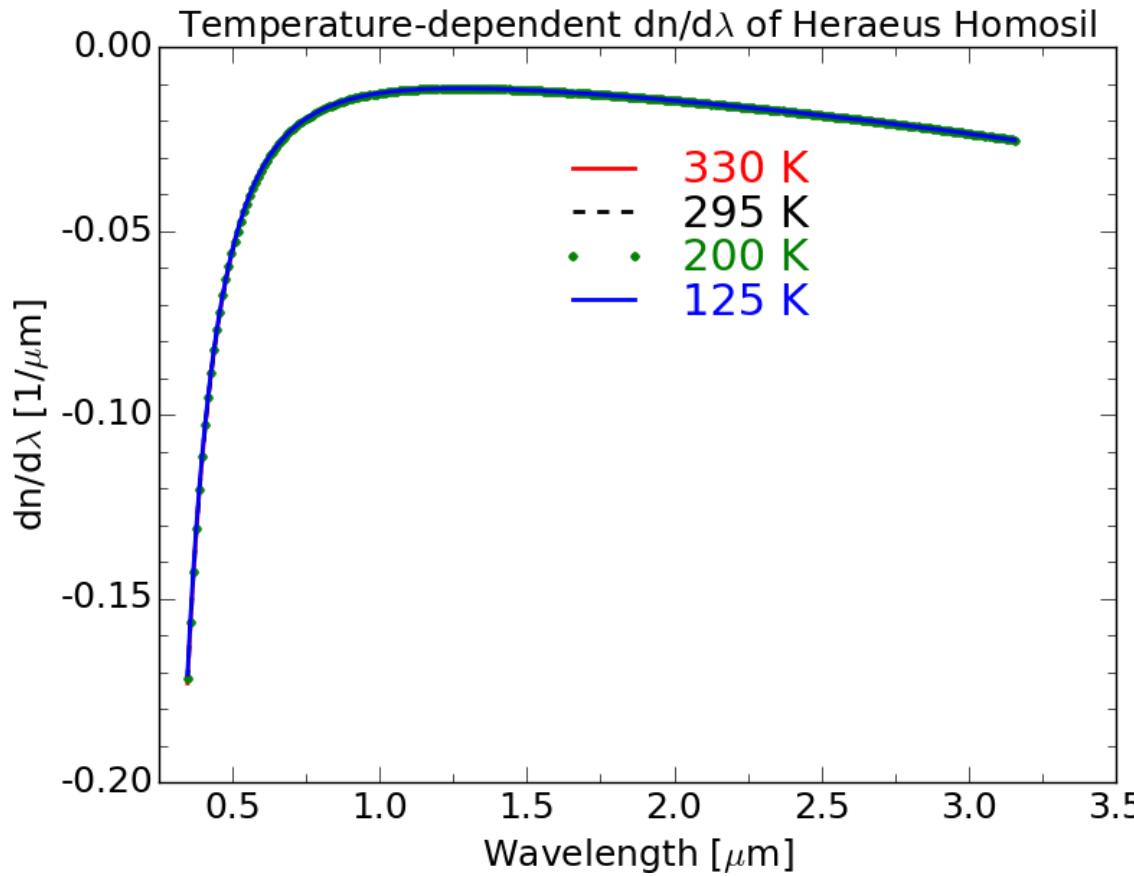
$$S_i(T) = \sum_{j=0}^3 S_{ij} \cdot T^j$$

$$\lambda_i(T) = \sum_{j=0}^3 \lambda_{ij} \cdot T^j$$

$$AAR = \frac{\sum_{k=1}^n |index_{measured} - index_{fit}|}{n}$$

Homosil_AAR = 5.07×10^{-6}

Derived Properties of Heraeus Homosil



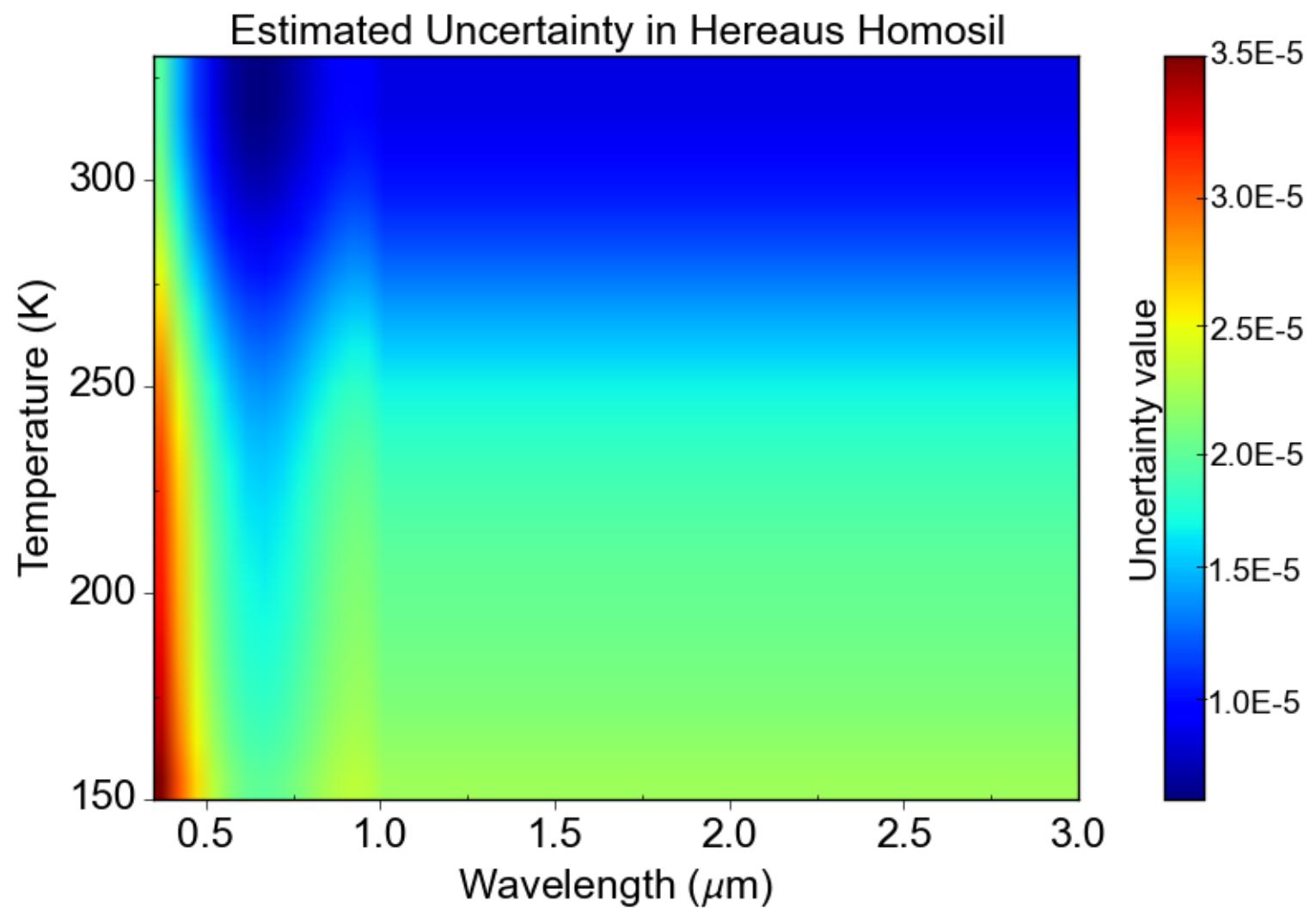
Example of Bookkeeping Error Budget

| index n | apex α | deviation δ | dn/dλ | dn/dT | dn/da | dn/dδ | dλ | dT | da | dδ | → | dn | | | | | | | |
|---------|----------|-------------|------------|------------|------------|------------|------------|-----------|---------|---------|-------|---------|-------------|---------|------------|-------------|---------|-------------|---------|
| 1.4574 | 10.0 deg | 0.175 rads | 4.595 deg | 0.080 rads | 0.00040/nm | 0.000120/K | -2.64/rad | 5.690/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -6.4E-06 | 0.00150 deg | 5.4 sec | ### 1.5E-04 | 1.7E-04 |
| 1.4574 | 20 | 0.349 rads | 9.319 deg | 0.163 rads | 0.00040/nm | 0.000120/K | -1.35/rad | 2.786/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -3.3E-06 | 0.00150 deg | 5.4 sec | ### 7.3E-05 | 9.5E-05 |
| 1.4574 | 30 | 0.524 rads | 14.321 deg | 0.250 rads | 0.00040/nm | 0.000120/K | -0.93/rad | 1.789/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -2.3E-06 | 0.00150 deg | 5.4 sec | ### 4.7E-05 | 7.4E-05 |
| 1.4574 | 40 | 0.698 rads | 19.796 deg | 0.346 rads | 0.00040/nm | 0.000120/K | -0.73/rad | 1.267/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -1.8E-06 | 0.00150 deg | 5.4 sec | ### 3.3E-05 | 6.4E-05 |
| 1.4574 | 50 | 0.873 rads | 26.038 deg | 0.454 rads | 0.00040/nm | 0.000120/K | -0.63/rad | 0.932/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -1.5E-06 | 0.00150 deg | 5.4 sec | ### 2.4E-05 | 5.9E-05 |
| 1.4574 | 58 | 1.012 rads | 31.912 deg | 0.557 rads | 0.00040/nm | 0.000120/K | -0.58/rad | 0.730/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -1.4E-06 | 0.00150 deg | 5.4 sec | ### 1.9E-05 | 5.6E-05 |
| 2.6 | 10 | 0.175 rads | 16.195 deg | 0.283 rads | 0.00040/nm | 0.000120/K | -9.27/rad | 5.588/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -2.3E-05 | 0.00150 deg | 5.4 sec | ### 1.5E-04 | 1.7E-04 |
| 2.6 | 15 | 0.262 rads | 24.677 deg | 0.431 rads | 0.00040/nm | 0.000120/K | -6.27/rad | 3.603/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -1.5E-05 | 0.00150 deg | 5.4 sec | ### 9.4E-05 | 1.2E-04 |
| 2.6 | 20 | 0.349 rads | 33.678 deg | 0.588 rads | 0.00040/nm | 0.000120/K | -4.80/rad | 2.569/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -1.2E-05 | 0.00150 deg | 5.4 sec | ### 6.7E-05 | 9.1E-05 |
| 2.6 | 25 | 0.436 rads | 43.491 deg | 0.759 rads | 0.00040/nm | 0.000120/K | -3.95/rad | 1.910/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -9.7E-06 | 0.00150 deg | 5.4 sec | ### 5.0E-05 | 7.7E-05 |
| 2.6 | 30 | 0.524 rads | 54.587 deg | 0.953 rads | 0.00040/nm | 0.000120/K | -3.42/rad | 1.429/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -8.4E-06 | 0.00150 deg | 5.4 sec | ### 3.7E-05 | 6.7E-05 |
| 3.4 | 10 | 0.175 rads | 24.475 deg | 0.427 rads | 0.00040/nm | 0.000120/K | -13.95/rad | 5.479/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -3.4E-05 | 0.00150 deg | 5.4 sec | ### 1.4E-04 | 1.6E-04 |
| 3.4 | 14 | 0.244 rads | 34.958 deg | 0.610 rads | 0.00040/nm | 0.000120/K | -10.11/rad | 3.734/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -2.5E-05 | 0.00150 deg | 5.4 sec | ### 9.8E-05 | 1.2E-04 |
| 3.4 | 18 | 0.314 rads | 46.265 deg | 0.807 rads | 0.00040/nm | 0.000120/K | -8.03/rad | 2.707/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -2.0E-05 | 0.00150 deg | 5.4 sec | ### 7.1E-05 | 9.6E-05 |
| 3.4 | 22 | 0.384 rads | 58.895 deg | 1.028 rads | 0.00040/nm | 0.000120/K | -6.75/rad | 1.994/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -1.6E-05 | 0.00150 deg | 5.4 sec | ### 5.2E-05 | 8.0E-05 |
| 4.0 | 10 | 0.175 rads | 30.806 deg | 0.538 rads | 0.00040/nm | 0.000120/K | -17.48/rad | 5.377/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -4.3E-05 | 0.00150 deg | 5.4 sec | ### 1.4E-04 | 1.6E-04 |
| 4.0 | 12.5 | 0.218 rads | 39.130 deg | 0.683 rads | 0.00040/nm | 0.000120/K | -14.13/rad | 4.134/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -3.5E-05 | 0.00150 deg | 5.4 sec | ### 1.1E-04 | 1.3E-04 |
| 4.0 | 15 | 0.262 rads | 47.947 deg | 0.837 rads | 0.00040/nm | 0.000120/K | -11.92/rad | 3.267/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -2.9E-05 | 0.00150 deg | 5.4 sec | ### 8.6E-05 | 1.1E-04 |
| 4.0 | 17.5 | 0.305 rads | 57.461 deg | 1.003 rads | 0.00040/nm | 0.000120/K | -10.39/rad | 2.608/rad | 0.10 nm | 4.0E-05 | 0.1 K | 1.2E-05 | 0.00014 deg | 0.5 sec | # -2.5E-05 | 0.00150 deg | 5.4 sec | ### 6.8E-05 | 9.5E-05 |

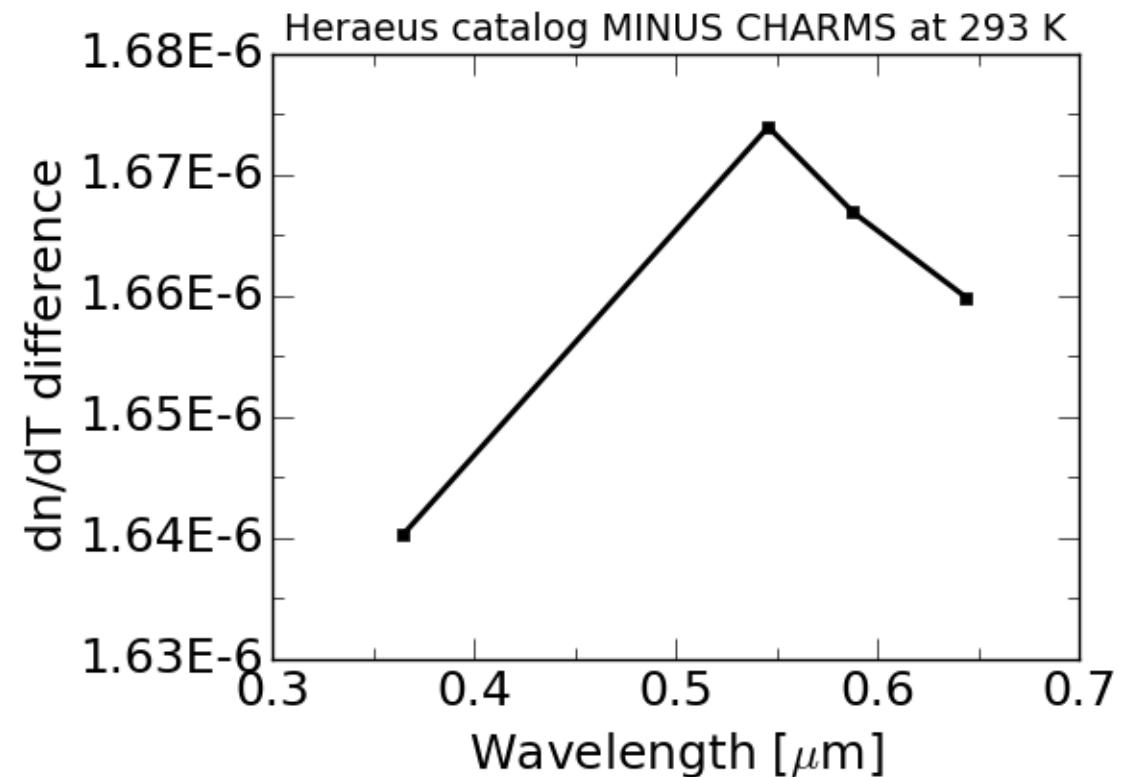
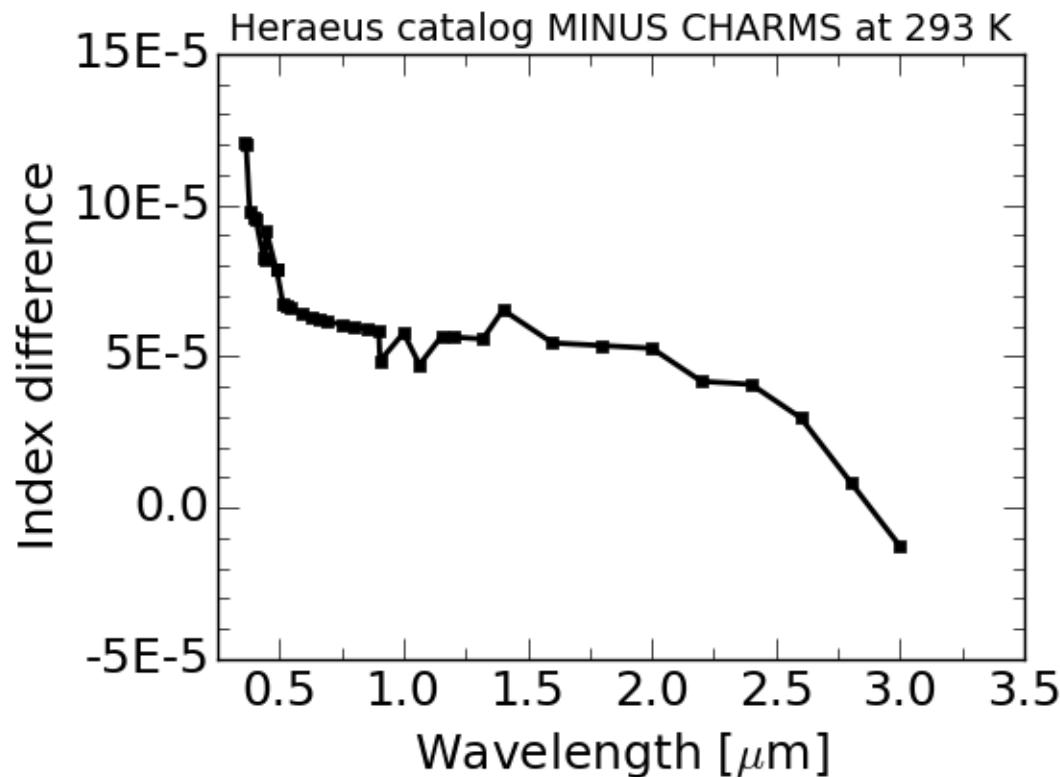
- uncertainty governed by all eight quantities in the red box for each measurement for a given specimen (green box)

so, a refractometer should not list a single number for accuracy

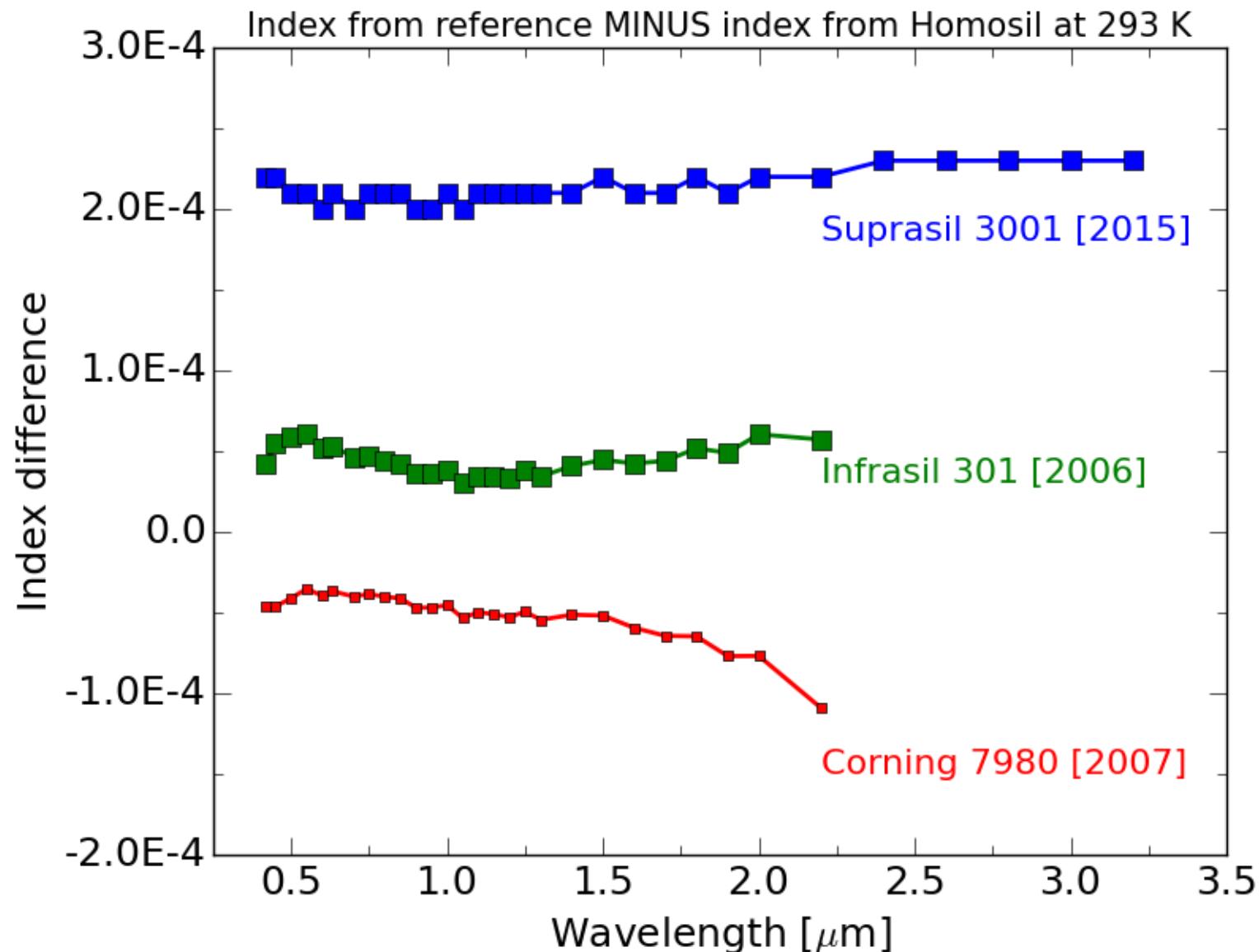
Measurement Uncertainties



Comparison of Heraeus Catalog with CHARMS

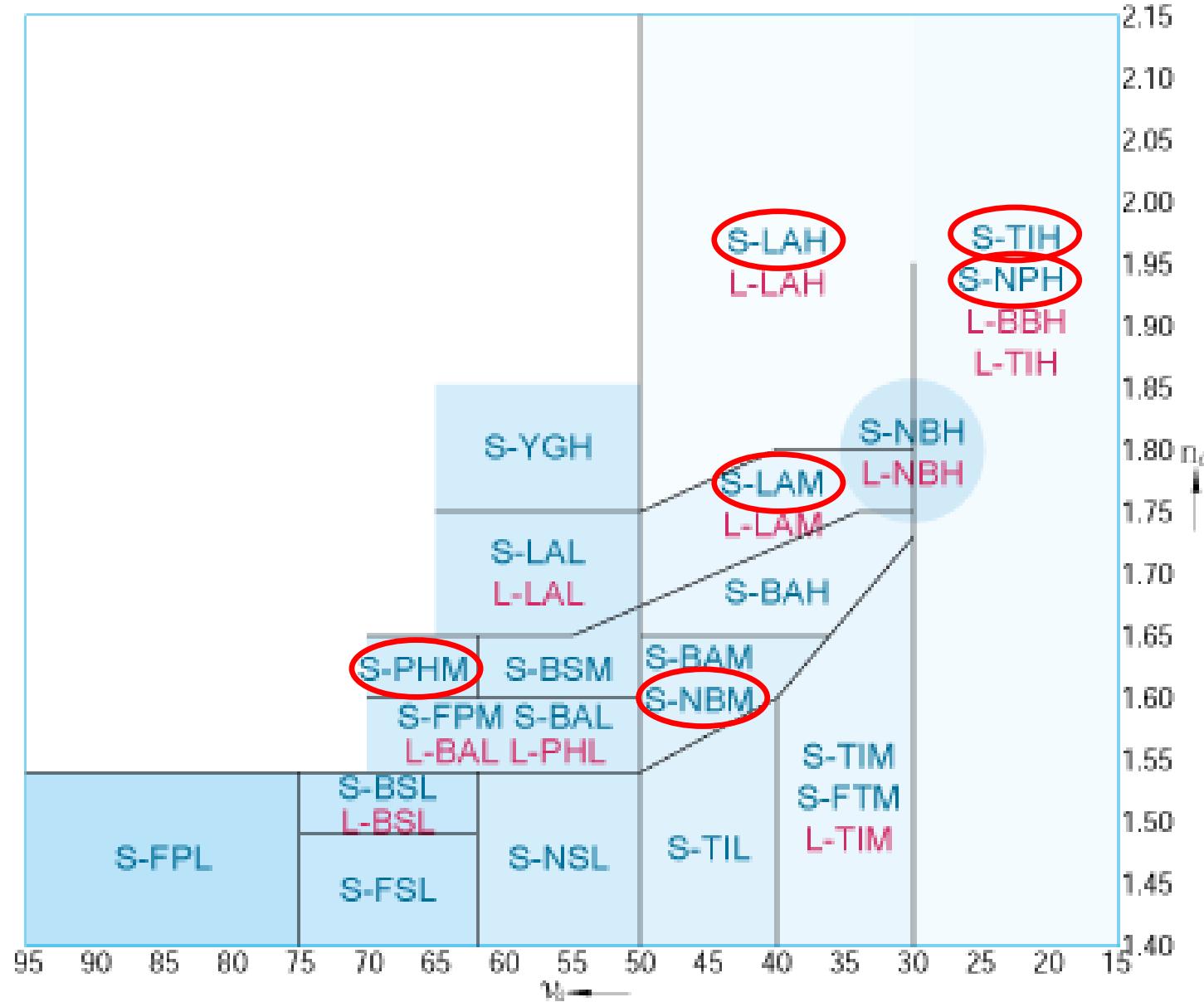


Comparison with other fused silica-based glasses



Backup

Ohara Glasses



Ohara nomenclature example:

Environmentally “safe”

“H” for
high index

S-LAH59

Number of glass
within given family

Most important chemical
elements contained